

Geographic information systems and site selection issues of open sea cage culture

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The GIS paradigm

As is much known in the Information Technology circles, a pair of numbers narrates the past, describe the present and in fact most importantly seal the future. The pair obviously means the latitude and longitude of the location any where under the sky. This perspective of referencing any type of information be it scientific, sociological, psephological or economic, has taken the world of analytics by storm in past quarter of a century. The last decades of the previous millennium were dotted with spurt in methodologies and software which were totally dependent on this type of geo-referenced data. Information collected serially over time, popularly known as time series, always had a huge role to play in studying the impact of changing eras and centuries at larger level and seasons and cycles in shorter duration. The surreptitious shadow cast by the effect woven by time on the trait of interest had always caught the imagination of analytical computational experts, especially econometricians. Similar to the perpetual latent impact of temporal causes, the geographic factors also have been exhibiting impact on many an important scientific phenomenon. Most of the natural resources available on earth are bound to be impacted by their geographic position on the earth's crust. This is best explained by the availability of resources like ores and mines in certain pockets on earth. Though geological reasons arising from

the core of earth are reasons for their pattern, the external environment like the atmospheric parameters and other natural habitation like forests etc have a very important role in moderating their availability. Hence the idea of viewing the geographic location as another latent cause of expression of any important parameter alongside temporal references started clawing up on the ladders of analysts and a whole new vista of analytical reasoning emerged. That vista loosely named as analysis of geo-referenced series or spatial analytics has a very important requirement, a series of spatially referenced data spread across temporal spectrum. The series of spatio- temporally arranged data points are popularly referred to as Geographic Information System or GIS in short. When originated the GIS concept was mostly applied to terrestrial references. The absoluteness with which the terrestrial data points could be uniquely referred by a pair of geographic coordinates amply suited the development of databases which were strongly rooted on those coordinates. Hence a plethora of application-ware were developed which led to the possibility of developing maps on the digitised geographic platform showing various intensities with which the parameters of interest were available. These maps are popularly referred to as "Thematic Maps" and they formed an essential part of many a dossier on resource spread, intensity and availability. But GIS is much more than development of

thematic maps. The range of applications is multifaceted including geo statistics, modelling and development of decision support systems.

Although terrestrial GIS has been quite in vogue in the past quarter century or so, the last decade saw the emergence of another dimension to it, literally. The Marine Geographic Information System (MGIS) has the added dimension of depth alongside the latitude and longitude. It has been a much discussed and researched topic that the marine fauna and flora demonstrate huge diversification down the bathymetric locales. Marine GIS must first adapt to the characteristics of the marine world and marine data and the dynamic relations among the various components of the marine environment. Thus MGIS opens up a new world of opportunity as well as challenge which is 3 dimensional to say the least.

At this juncture the importance and utility value of 3D marine data sets as compared to the lat- long based terrestrial datasets have to be clearly understood. The depth component, needless to add, holds the key towards unravelling a huge treasure of wealth and its dynamics across the geographic vastness as well as their vertical upheaval. Such a three coordinate time series can always aid in shoring up the onerous task of studying the underlying interrelationships, trend, seasonality etc., which classically suit spatio-temporal analyses. Such a system can mutually embellish species life history data which in turn can aid in lucid portrayal of the progression down the prey- predator web. The interlinked nature of coastal, oceanic and fisheries information is for everybody to understand and study. The invaluable contribution that such a marine GIS can make while attending to the conflict between marine object dynamics and management policies is anybody's guess. Another topic worthy of discussion is the type of input getting into a marine GIS including those obtained by meteorological gadgets as well as by Global Position Systems. A variety of technical disciplines and issues are associated with the

nucleus of marine GIS technology. It is quite constructive to have stress on the importance of meta data while detailing the basic types of data on the very first occasion.

The goal of marine GIS has always to be kept in mind before trying to understanding the technical intricacies. Ranging from exploratory input to full fledged predictive paradigms, the MGIS has a huge chunk of goals which could be attained using specially drafted software. The core concepts of MGIS starting from location up to diffusion have strong relationship with various types of information collected at various stages of the resource regeneration system. One standout example that could be cited is the association of regions using chlorophyll contents and sea surface temperature. Another way of looking at this whole paradigm is to pose self quizzing queries and seeking answers like, "Where was it"; "How long was it existing?"; "Is there any other resource abundant nearby?" etc. A model which satisfactorily answers the above asked questions would be the one which would be the best.

MGIS and Oceanography

GIS in general and MGIS in particular are affronted by Oceanographic concepts in many ways. The extent of influence can be well understood by the simultaneous consideration of micro scale turbulence to enormous gyres, both of whom have a serious role to play in shaping up the Information System. The role of Remote Sensing in these oceanographic data consideration has also been a topic of discussion and debate. Needless to say a management interface for coastal and oceanic environment is a much needed reality for any nation caring for justifiable exploitation of its resources. No better argument is needed for this aspect of exposition than the fact that 90% of pollutants generated by economic activities end up in coastal zone. It is a matter to ponder that the historic reasoning behind oceanic upheavals and their vulnerability to climate change which is a present day priority, have been comprehensively juxtaposed. The

inevitability of viewing the coastal zone from the stakeholder's point of view in the holistic perspective rather than a fractured sector by sector basis can never be understated.

Innumerable citations and references are available for the linking of oceanographic parameters with a MGIS. Starting with datasets vis-à-vis their relevance to marine geology to information based accrued over hydrological sounding and multi-beam sonar systems, the review could be elaborate and informative. Please refer V. Valavanis (2002) for an excellent review.

The role of GIS in flood assessment is another important facet full of references on digital elevation models, geographic flood information system and the world map of natural hazards. The citations available in Valavanis (2002) sufficiently sum up the efficacy and range of the tool.

An exposition on the application of GIS in coastal and oceanic management throws up interesting works like Natural Resources Management Facility for Mozambique, which primarily aim at social development like employment generation and poverty alleviation through participatory and sustainable management of natural resources. Certain attempts to rank coastal regions on their environmental sensitivity and pollution hazard with the help of GIS have also been discussed in literature.

Throwing spotlight on yet another facet of GIS, work done by researchers across the globe by integrating hydrodynamics and morphometry are worth revisiting (Valavanis (2002)). The analytics done in describing a dynamic coastal zone like a lagoon ecosystems along with identification of main aspects of their degradation and identification of critical environmental parameters as also recovery plan will really spur the researcher towards seeking more on this application of GIS.

There are multitudes of references on GIS application for study of oil spills in oceans, sea level rise and natural and

artificial reefs which are bound to add strength and objectivity to the more publicized perception on GIS. Popular techniques like ecological modelling, scenario building and vulnerability index computation on a geo referenced platform have also been some of the much highlighted applications of MGIS. The MGIS is also a widely used tool to study and manage lesser focussed marine contingents like submerged aquatic vegetation, wetlands and watersheds.

Literature is replete with initiatives taken by various governmental and research establishments towards Oceanographic GIS. The developments in the Gulf, US and Europe have been worth chronicling (Valavanis (2002)). But the flagging of GIS as a solution to the ever increasing data volume and complexity should be approached with caution, as *prima facie* the statement indicates data redundancy and Information Systems target something primarily different. The issue of handling voluminous datasets usually target solutions in the mould of data warehousing and Information Systems should not be equated with them.

In all there are around 20 unique efforts carried out at various locations across the globe till the turn of the last millennium Valavanis (2002). Most of the information systems mentioned are of very high environmental importance and their role in arriving at multidisciplinary answers to important scientific and societal queries can never be understated.

Any logical extension of global examples of MGIS would be the focus on data sampling methods which broadly outlines the gadgetry involved in the collection of physical, chemical and biological data that add up to make the system. The point that commercial establishments have fanned out their research and analytical wings across the globe to sustain their interests through Oceanographic trend monitoring, is probably one single stand out fact. It effectively sums up the impetus being thrust on this branch of study and the enormity of changes and paradigm

shifts which are just round the corner. The information on various satellite sensors and the corresponding internet sources are real highs which have augmented the reach and purpose of MGIS. The development of other sources of remote sensed data like sensing platforms, Ocean Data Acquisition System etc. is a meticulous collation on advances in Oceanographic data sampling. Plethoras of urls in the internet have comprehensive information regarding the details of the gadgets.

Another interesting issue discussed during the course of this topic is the one pertaining to real-time organisation of marine survey data. Though it may sound similar to the type of data integrations discussed so far to an innocuous reader, this throws up more light into the integrated analytics that follow the online data accumulation. Hardware innovations like tape robot is undoubtedly a fascinating interlude to this, but it has the capability to derail a serious analytical researcher by leading him into the fascinating world of clustered data storage management.

This discussion could be rounded off with a detailed exposition on the methods and techniques adopted in identification and quantification of gyres, classification of surface waters, identification of temperature and chlorophyll fronts and tracking and measurement of upwelling. The mode of discussion is a judicious admixture of generic introduction followed by specific examples of the techniques application across the globe. The description of the unified efforts involved in the mapping of sea beds where local and remote methods of data derivation come to the fore cited in Valavanis (2002), could aptly wrap up the extensive discussion on GIS and its application in Oceanography.

MGIS and Fisheries

MGIS with a firm footing on various sources of information is obviously well poised to have many applications in the fisheries sector which have direct impact on the fisher

folk. Unlike hydrology and other physicochemical parameters, fish capture and availability based indicators have a very huge say on the holistic management of fisheries encompassing social, economic, technical, ecological and ethical aspects. Any information system that has roots on this type of core information will have a whole lot of relevance and priority amidst its class of systems. Naturally more criticisms and evaluations are bound to tow them. The Net is replete with references wherein umpteen instances of applications based on MGIS coming to the aid of fisherfolk and planners in various countries. Interestingly another interesting aspect of the link between Information Systems and Fisheries is the role of geostatistics (spatial statistics) which is an established branch of statistics inquiry into the geo referenced datasets. Albeit tools like kriging and variograms have been in vogue in the GIS universe they are basically statistical tools which are adopted or adapted to suit to the requirements of geo referenced datasets.

A large number of techno-administrative information consortia formed across the world catering to the fisheries GIS (Valavanis (2002)). The chronological developments that have taken place in the electronic documentation and documentation of strides made by this branch of IT are worth browsing through. The first GIS conference at Seattle in 1999 is a proof for this. While reiterating the intricacies involved in the comprehensive understanding of the relationship of fish and its environment, the conference stressed that it is time to have a syndicated effort to publish scholastic efforts in this direction. The statement – “The time has arrived for a Fisheries GIS journal...” made by the participants (although it was made in early 2000's) sums up the sincerity with which this document is prepared. Although the trickles which were chronicled in many publications have turned into a stream nowadays, an exclusive periodic publication of articles on GIS for marine fisheries is still elusive.

The four stages at which GIS on fisheries can be utilised are worth underscoring. Most of the planning and policy

compilers get saturated with the thematic maps and conceptual 3D output generated by GIS software. The other stages viz. which area meets the set requirements, presence or absence of a pattern over space and scenarios which can arise as a result of decisions and regulations are weightier in purpose but less in vogue when it comes to utilisation. Hence it is mandatory for any discussion on adoption of GIS to equally stress all the four levels of the tool's application. One important aspect to be highlighted on marine fisheries management through GIS is a citation of Senegalese case (Valavanis (2002)) which can be quite useful in the context of any similar footed nation. GIS was utilised to identify areas of conflict between artisanal and industrial fisheries and further proceeding on to the explanations for fisheries management on the degree of respect for the limits of regulated fishing areas and spatial fishing strategies as per the major seasons. The development of bioenergetic physiological principles augmented generalised spatial dynamic age structured multistock production model is a refreshingly new vista of GIS application in fisheries research. As another application of GIS in marine fisheries management, the mapping of biomes, large marine ecosystems etc. which go a long way in evaluating and explaining the distribution of marine features (e.g. primary production), which are not usually focussed upon under conventional studies can be mentioned. In a way there is an exhaustive collection of references which unravels all the possible utility areas of GIS in marine fisheries management (Valavanis (2002)).

The role of GIS in aquaculture needs no further emphasis as it is almost similar to the terrestrial GIS wherein primary role is in site selection. Herein come the issues of planning, designing and execution of aquaculture assignments, apart from simulation backed economic forecasting tools, which is a real plus for observers with less exposure.

During the turn of last century some working models to manage and study thriving inland fisheries like freshwater

salmon fisheries were developed (Valavanis (2002)). The discussion includes inclusion of environmental variables alongside the classical parameters like expanse of water bodies etc. which gives a ringside view of initiatives made in the first part of this decade.

The use of remote sensing tools in the applied portion of data collation is another aspect of study. The grid construction and partial ground truthing of the remote recordings are all inseparable parts of this methodology and they can always be adequately described with the help of certain specific studies whose outputs like maps etc. have been provided (Valavanis (2002)). A list of more than 60 Internet sources of GIS databases embellishes the chapter and it has been one of the unique plus points of this book as such. A couple of snapshots from some GIS databases which include very pertinent theme maps like gear pressure on cephalopod populations in SE Mediterranean and catch areas of Octopus in the same area are excellent techniques to communicate with the starter Valavanis (2002). Developments like mapping of spawning grounds, essential habitats, migration corridors etc. which give a taste of how powerful and useful GIS can be in a fishery planner's hand.

MGIS and cage culture

Open sea cage culture being an operation wrought with a lot of uncertainties ranging from physical parameters of the ocean to the biotic and chemical factors affecting the morbidity and mortality rates of the animals to be cultured has to be necessarily based on informed plan. An informed plan is one where studied decisions are taken before the blue print is prepared which in turn are based on various parameters of concerned recorded pertaining to the area of operation. Hence when the ocean can pose challenges at least on three dimensions with a whole lot of physical and chemical parameters on the tow. It is here the role of a geo- spatial aggregation of parameters comes to prominence.

Site selection for cage culturing exercises will involve specific inputs on the following parameters:

- (i) Bathymetry
- (ii) Currents
- (iii) Shelter and
- (iv) Water Quality Variations

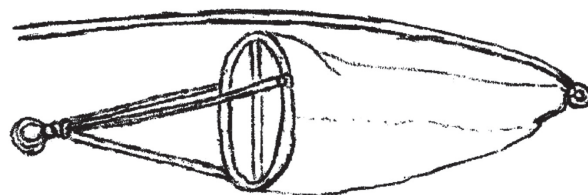
To explain this with an example to have a cage culture study based on Salmonids, it is essential to gather information on depth (m), current ($m\ s^{-1}$), dissolved oxygen ($mg\ l^{-1}$), salinity (%) and temperature ($^{\circ}C$). From established literature inputs on the possible range and optimum values of these parameters might have to be collected. Such data coupled with topography of the site and exposure of the same would be used in the site assessment.

Towards achieving this preliminary studies conducted in the area focussed have to be collated and compiled. Then suitable software to store/ update and analyse the data may have to be selected. This software could range from free to very cheap shareware to software meant for educational/ research institutions to full fledged commercial software like Arc GIS etc. As the next step the topography of the broader location where cage is planned to be set up along with the nearby coast details like bay etc should have to be mapped. The outline map of the greater area like bay could well be a definitive starting point. Suitably scaled maps have to be drawn outlining the broader area of focus.

The second task is to generate a bathymetric contour map of the broader area of interest which could be achieved by making a series of boat transects at constant velocity and bearing using echo-sounders. Depths such recorded could be plotted onto the base map.

The third task of measuring the velocity of currents is done by using hydrographic drogues (sea anchors) (displayed below).

Drogue / sea anchor



The drogues could be located at timed intervals from boats using sighting compasses.

The fourth parameter of exposure could be categorised by estimating wave heights at different locations. Expected wave heights depend upon water depth and wind velocity, duration of fetch over which wind passes before impacting the proposed location.

The wind data could be obtained from nearby weather stations.

The physico-chemical properties of the water like dissolved oxygen, temperature and salinity could be recorded at a number of fixed locations at different stages of tidal cycle using instruments like Oxygen meter and inductive bridge salinometer.

The whole database in GIS pertaining to the area under focus should preferably be prepared in two scales which are significantly different in resolution, something like 25 x 25 metre block or 10 x 10 m block based.

In any typical GIS software the different types of information like outline map, points of observation, bathymetric data, current and exposure data are entered in the form of different layers called grids. Usually the base grid containing the blocks is kept transparent and the other observed data sets are over laid on them either as points or shapes or themes.

Apart from these specific information that needs to be known for the type and size of cages, general information

of the broader area like pollution, availability of power (electricity) and presence or absence of tourist-related or ecological limitations.

In the following series of pictures provided in the paper by Ross et al (1993) graphically explains the details of one such GIS mapping done to locate suitable ambience for Salmoid cages.

For proceeding further the following are the parameters estimated during the exercise.

- (i) Mean depth : 6.8 m
- (ii) Current velocity : Upto 138 cm s⁻¹
- (iii) Speeds falling in acceptable range : 80%
- (iv) Nature of velocities: High at periphery; low near centre

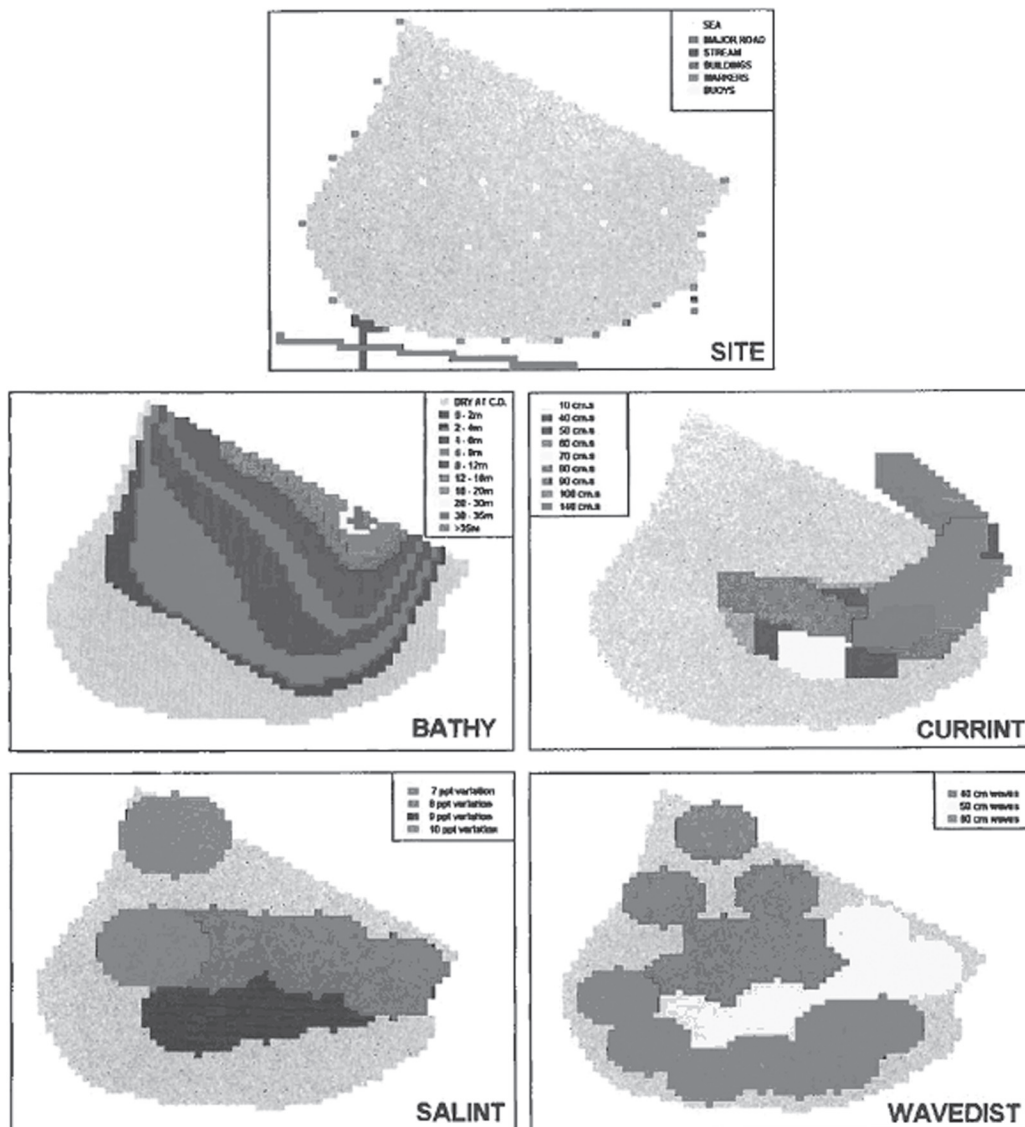


Fig. 2. The base map, SITE, digitised in OSU MAP.

Fig. 3. The bathymetric map of Camas Bruaich Ruaidhe, BATHY.

Fig. 4. Interpolated current distribution in Camas Bruaich Ruaidhe, CURRINT.

Fig. 5. Interpolated salinity distribution in Camas Bruaich Ruaidhe, SALINT.

Fig. 6. Interpolated wave height distribution in Camas Bruaich Ruaidhe, WAVEDIST.

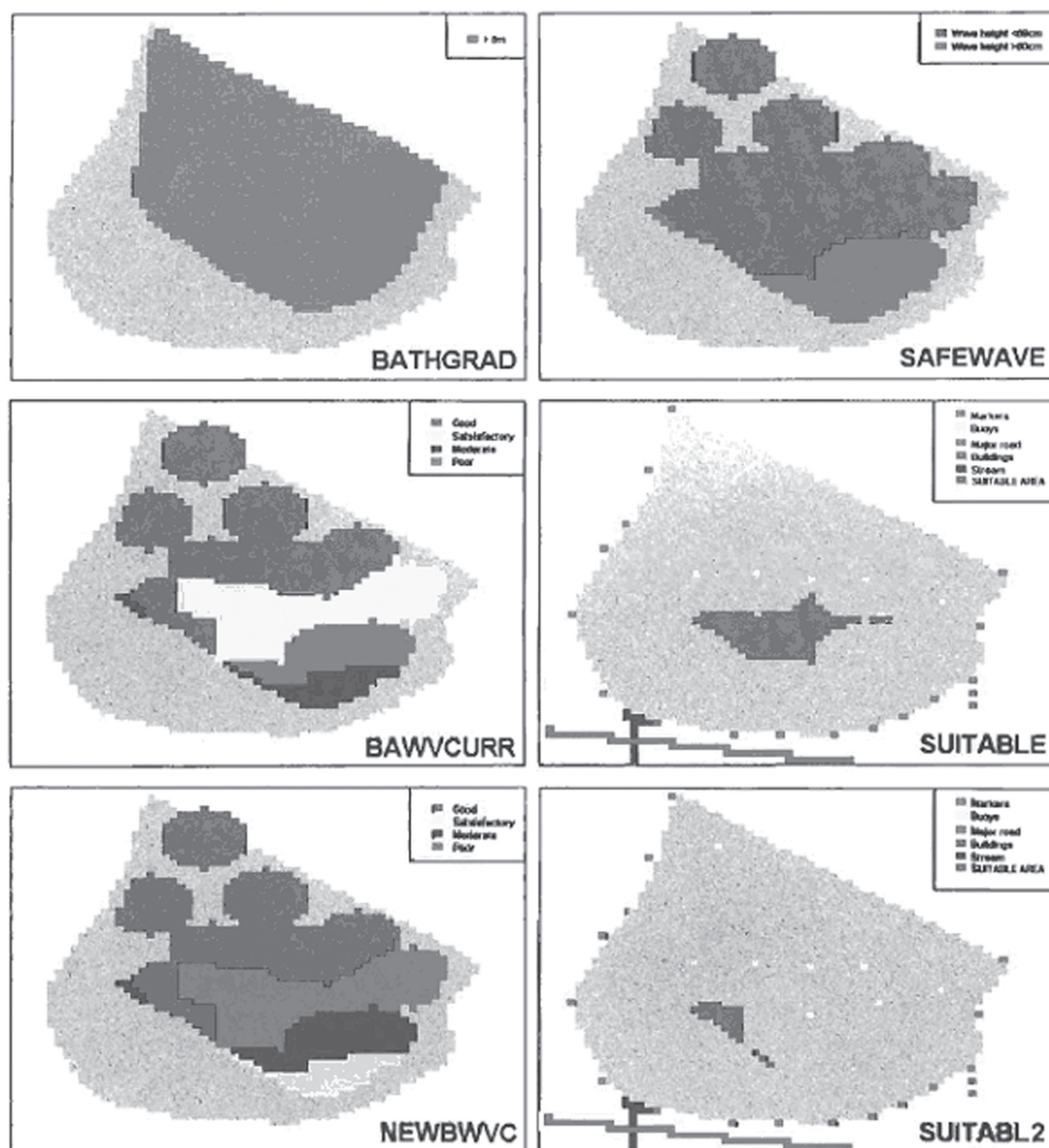


Fig. 7. Area suitable for cage installation based on bathymetry, BATHGRAD.

Fig. 8. Area suitable for cages based on bathymetry and wave heights, SAFEWAVE.

Fig. 9. Area suitable for cages based on bathymetry, wave heights and currents, BAWVCURR.

Fig. 10. Optimum area selected for cage installation, using the criteria given in the text, SUITABLE.

Fig. 11. Area suitable for cages based on bathymetry, wave heights and currents, recalculated using different selection criteria, NEWBWVC.

Fig. 12. Optimum area selected for cage installation, using the selection criteria applied in Fig. 11, SUITABL2.

- (v) Spatial interpolation: CURRINT
- (vi) Dissolved Oxygen levels: 8.6 to 11.0 ppm (at high tide) ; 8.2 to 10.4 ppm (at low tide) (no difference between surface and bottom readings)
- (vii) Water temperature: 12.8C to 13,4 C and 12.9C to 13.0 C at high and low tide respectively. (well within the tolerance level)
- (viii) Salinity parameter: 19% to 29%
- (ix) Wind speeds: 61 km h⁻¹ and 85 km h⁻¹
- (x) Fetches observed 4.44 (NW), 3.42(NE) and 2.37 (NE) were the longest
- (xi) Wave heights: 0.4 to 0.8 m

Based on the type of data collected over a reasonable period of time scorecard was prepared for the site selection. The scores with not more than two to three outputs were decided based on the various parameters discussed above and the highest score is given to the blocks which have the most favourable parametric value.

Finally to decide on the suitable block (25 x 25 m) or (10 x 10m) the interpolated wave heights coupled with bathymetry will decide the score on the depth aspect. Similar recoding based on the scores for other parameters like water quality was conducted and the most ideal pocket was selected based on the pocket/ block which scored the maximum. (SUITABLE in the picture shown above).

While this method seems to be straight forward and deeply rooted in the classical analytical traditions, the

over dependence of the precision of parameters estimated makes it overtly vulnerable to instrument/ equipment errors. But one huge plus for this approach is the avoiding of individual bias and subjectivity while zeroing in on the location of choice. Still unfavourable locations can be removed at the outset by way of observing cage depth and limiting beyond 1.5 times of the depth. Such dictums like avoiding velocities less than 5 cm s⁻¹ and those above 50 cm s⁻¹ should be built keeping in mind the species to be cultivated. The sequences to be followed in the decision making process should be ceremoniously followed for any interchange of layers may produce different output.

With the advent of brutal computational power the process of decision making especially the computations involved are of no big threat. But an assiduous selection of decisive parameters and careful measurement of parameters during survey is a must for any successful use of MGIS technique for selecting Cage locations for mariculture.

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